ANTENNA HANDBOOK

Radio Canada International

INTRODUCTION

As a shortwave listener you would no doubt prefer to hear every distant broadcast with the clarity and fidelity of your local AM radio. Given the number and variety of obstacles that confront a radio signal on its path between broadcaster and listener, that is unlikely to happen. However, you *can* take many steps to improve reception. Some steps may be as easy as changing frequencies or listening times, or the location of your receiver. Others are more complicated, such as building an antenna.

Most of this handbook is devoted to antenna use and construction, but it also includes information about basic radio principles. Whether your shortwave receiver is an economical portable or an expensive tabletop, we trust Radio Canada International's *Antenna Handbook* will increase your knowledge and enjoyment of shortwave broadcasting.

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HOW RADIO WAVES TRAVEL

An antenna is a conductor capable of radiating or receiving energy. For example, RCI's transmitters in Sackville, New Brunswick, convert electric energy into electromagnetic (radio) waves that are radiated outward by the antennas at the speed of light—approximately 300,000,000 metres per second (186,000 miles per second). A receiving antenna converts these radio waves into electric energy which is interpreted by the electronic circuits in your receiver and transformed again into voices and music.

Wavelength and Frequency

The terms wavelength and frequency are used interchangeably to denote the presence of radio energy in some part or at some point in the Radio Frequency Spectrum: they are different units of measurement closely related to each other. Let's start with wavelength. Although all radio waves travel at the speed of light, they vary in length from fractions of a centimetre to thousands of metres. The wavelength of a shortwave frequency is expressed in metres.

Frequency is the number of cycles (or waves) per second emitted by an antenna.(See Figure 1.) Cycles per second is abbreviated to Hertz (in honour of Heinrich Rudolf Hertz, the German physicist who discovered electromagnetic waves in

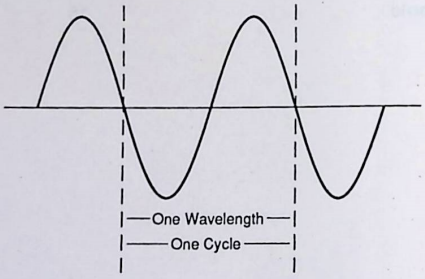

Figure 1

1888.) One thousand cycles per second is therefore expressed as one kilohertz (kHz) and one million cycles per second is one megahertz (MHz). RCI's program schedule lists frequencies in kilohertz. At the beginning of each broadcast, however, we identify the signal in both kilohertz and the metre band in which it is located.

The relationship of the speed of a radio wave, its frequency and its wavelength is expressed mathematically in the following equation:

$$\text{Wavelength} = \frac{\text{speed}}{\text{frequency}}$$

The speed of light is a constant (300,000,000 metres per second). Wavelength and frequency are variables; if we know one, we can determine the other. Suppose we wish to determine the wavelength of a radio signal whose frequency is 15,325 kHz.

$$\text{Wavelength} = \frac{300{,}000{,}000 \text{ metres / sec}}{15{,}325{,}000 \text{ cycles / sec}} = 19.58 \text{ metres}$$

This frequency is located in the 19 metre band. Bands are discussed below.

As frequency increases, wavelength decreases. Shortwave broadcasting is often referred to as high frequency broadcasting.

Shortwave Bands

By international agreement a certain number of distinct "bands" of frequencies within the radio spectrum have been allocated for use by shortwave broadcast stations. These are located roughly between 2,000 and 30,000 kilohertz or 120 and 11 metres. (See Table 1).

Types of Radio Waves

Radio waves are emitted from an antenna in all directions, expanding outward similar to water ripples spreading out on the surface of a pond into which a stone has been thrown. While the rippled water metaphor helps us visualize how waves are propagated through space, the actual field pattern of a wave radiated from a vertical antenna more closely resembles a huge doughnut lying on the ground with the antenna in the hole at the centre. (See Figure 2).

Part of the wave moves outward in contact with the ground to

Metre Band	MHz Band	Frequency Range (kHz)
11	26	25,600–26,100
13	21	21,450–21,750
16	17	17,700–17,900
19	15	15,100–15,450
25	11	11,700–11,975
31	9	9,500–9,775
41	7	① 7,100–7,300
49	6	5,950–6,200
60	5	② 4,750–5,060
75	4	③ 3,900–4,000
90	3	② 3,200–3,400
120	2	② 2,300–2,495

Table 1

① Used in all areas of the world except the Americas.
② For use in tropical areas of the globe only.
③ For use in Europe and Asia only.

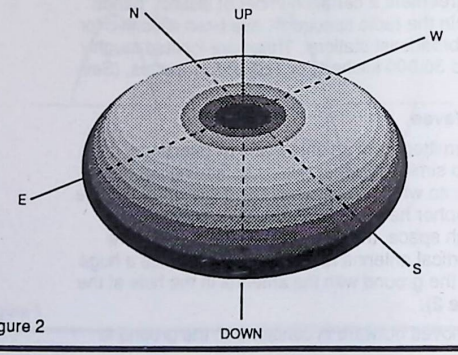

Figure 2

form a ground wave. The rest of the wave moves upward and outward to form a sky wave.

Shortwave transmissions are achieved by means of sky waves which broadcasters concentrate and direct at a region high in the earth's atmosphere called the ionosphere.

The Ionosphere

The ionosphere that encircles the earth 50 to 400 kilometres above the surface differs from the surrounding atmosphere in that it contains a much higher number of charged particles—positive and negative ions.

The ionosphere acts as a conductor, absorbing energy in varying amounts from the radio wave. But, more importantly, it also acts as a radio mirror, gradually refracting the sky wave back to earth. The effectiveness of this ionospheric mirror depends upon the angle at which it is struck by the sky wave, the frequency of the signal, and the ion density.

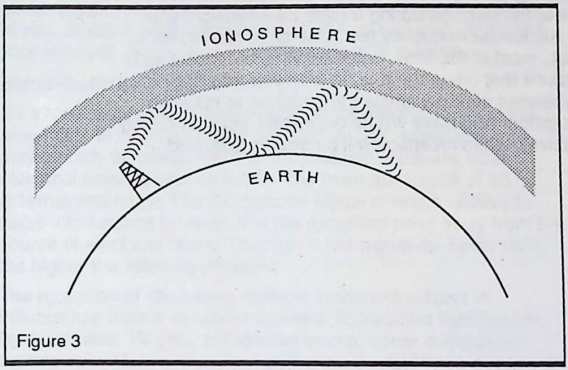

Figure 3

A sky wave, after it has been refracted by the ionosphere, can be reflected by the earth and directed toward the ionosphere once again. Each complete path—from earth to ionosphere and back to earth—is called a "hop." It's because of this multi-hop ability that shortwave radio signals are able to span continents and oceans with only moderate power. (See Figure 3.) Because the ionosphere is produced mainly by ultraviolet radiation emitted by

the sun, the amount of ionization varies with changes in solar radiation: it changes hourly, between day and night, seasonally, geographically, and over an 11-year solar cycle.
The constantly changing nature of the ionosphere obliges shortwave broadcasters to transmit the same program simultaneously on two or more frequencies and to periodically change frequencies to ensure the best possible reception. RCI, for example, catalogues its frequency changes in a program schedule issued twice a year.

If broadcasters were to change frequencies and target areas without consultation and mutual agreement, the result would be chaos. Instead, regular international notification procedures give all broadcasters a fair chance of reaching their chosen audiences at the desired times.

There are a number of generalizations surrounding the propagation of radio waves. For example: higher frequency signals travel best during the day and lower frequency signals travel best during the night. Therefore, if a broadcaster offers you a choice of frequencies during a night transmission, you should tune the lowest frequency first. Like all generalizations, this is correct...most of the time. But shortwave broadcasting is full of exceptions that prove the rule. In fact, you may have to change frequencies during a single transmission to maintain optimum reception. And there will be occasions, such as during high solar activity, when reception will be unavoidably bad.

HOW EXTERNAL ANTENNAS IMPROVE RECEPTION

If you have a tabletop receiver, you have no choice in the matter: you must erect an external antenna and connect it to the receiver via the antenna jack. If you have a small– or medium–sized portable receiver, you have a choice: to operate with the built–in whip antenna, or erect an external antenna. In the latter case, the big question is: will installing an external antenna improve reception? In most cases, yes, but unfortunately there's no absolute answer.

A shortwave radio capable of receiving weak signals over long distances is described as "sensitive." Most transistor portable receivers are designed for optimum sensitivity using the built-in whip antenna. Under normal reception conditions, therefore, the equipment should provide enjoyable listening. Poor reception can often be improved simply by placing the radio near a window or an exterior wall. However, if reception is only sporadically good, or you wish to expand the range of frequencies available to you, or you wish to capture a station that has thus far eluded your receiver, an external antenna is the only solution.

Signal-to-Noise Ratio

It's often thought that the main reason for erecting an external antenna is to increase signal strength. In fact, signal strength may already be adequate; the real problem is usually local electrical noise of various kinds. The main advantage of an external antenna is that it increases signal strength relative to noise interference by removing the reception point away from the source of electrical noise. The higher the signal–to–noise ratio, the higher the listening pleasure.

The reception of shortwave stations indoors is subject to interference from a variety of sources: fluorescent light fixtures, light dimmers, TV sets, microwave ovens, home computers, thermostats, electric motors, heating pads, etc. When a receiver and its built–in antenna are close to any of these noise generators, reception is likely to suffer.

Indoor reception can also be hindered by construction materials in the building itself. This is especially true of apartment buildings which have a lot of metal in their walls, floors and ceilings. This metal acts like a shield, reducing the strength of radio signals reaching the antenna—or even eliminating them completely. The

goal, then, is to place the antenna as far away as possible from noise sources and metallic shields.

Installation Tips

There are a few simple rules which govern the installation, materials and performance of almost any receiving antenna.

• *Height:* It should be at least 6 metres (20 feet) above the ground; higher is better.

• *Location:* It should be located as far away as possible from other buildings and utility lines. If utility lines are unavoidable, try to install your antenna at right angles to the telephone or power line to reduce noise interference.

• *Installation:* It must be securely fastened. An antenna that collapses upon a high voltage power line could cause serious damage. The most common anchor points are between houses, trees, utility poles, or ground. The ends of the antenna are tied to insulators. Insulators are tied to the anchor points by cord, rope or wire. Since a tree will likely sway in the wind, attach the insulator to a pulley and weight system to absorb movement and protect the antenna from strain and breakage.

• *Antenna wire:* Multi-stranded copper wire, 2–3 millimetres in diameter, is recommended. If you live in an industrial city, or near the sea coast, insulated copper wire is preferable to bare wire because it's protected against corrosion by salt air and smog.

• *Lead-in:* The antenna is connected to your receiver by a lead-in. The choices are regular insulated wire, shielded co-axial or flat twin-lead.

• *Joints:* All joints, such as between lead-in and antenna, should be soldered. Mechanical joints will corrode, resulting in loss of signal.

• *Grounding & Lightning protection:* High voltage can accumulate on the antenna during electrical storms, particularly if the antenna is long. Direct lightning strikes also pose a danger. Unless diverted to ground, high voltage will damage or destroy your receiver. The most effective lightning arrestor is the gas discharge type. It's expensive, but so is replacing a receiver.

While a lightning arrestor can protect an older receiver equipped with vacuum tubes, it is inadequate for a transistor receiver which can be damaged by even the small amounts of static electricity which accumulate on an external antenna—even when no electrical storm is underway. Transistor receivers require a

static arrestor which slowly and continuously discharges accumulated electricity. As a final precaution, always disconnect your antenna during storms or when you plan to be away from home for long periods.

Antenna Nomenclature

The performance and installation characteristics of antennas may be categorized in several ways. The most important are directivity and impedance.

• *Directivity:* An omni-directional antenna will receive signals equally well from any direction. A directional antenna must be oriented either at right angles to or parallel to the incoming signal.

• *Impedance:* The total opposition to current flow within a circuit is called impedance. Every antenna has a definite impedance value at the point where the lead-in is attached to it. Maximum energy transfer is only possible when the impedance of the antenna matches the impedance of the lead-in; and the impedance of the lead-in must also match the impedance of the receiver's input—usually 75 ohms.

• *Vertical / Horizontal:* A vertical antenna occupies less space but is more susceptible to atmospheric and local electrical noise than an horizontal antenna.

• *Narrow band / broad band:* A narrow band antenna is designed to capture a narrow range of frequencies.

• *End-fed / Off-centre-fed / Centre-fed:* These terms describe where the lead-in is attached to the antenna.

The antennas in the following pages can be built economically at home. The necessary materials—antenna wire, lead-in wire, insulators, lightning and static arrestors, rope, electrical tape, aluminum tubing, etc.—are readily available from most hardware or radio service stores.

If reception is still unsatisfactory after you have tried one or more of our proposed antennas, a more elaborate system may be the only solution. Your local radio service store can supply information on antennas appropriate for your particular area.

If you recently purchased a transistor portable receiver, you can probably get your first introduction to antennas without making a shopping trip at all. Most manufacturers now provide an antenna kit which includes 10 metres of insulated wire complete with terminal, insulator and connector.

While hardly robust enough for permanent installation, such kits are fine for experimentation at home or temporary installation while on a business trip or vacation. A horizontal antenna can be arranged on a balcony; a vertical antenna can be suspended from a window and held motionless by a weight at the bottom.

Let's start our detailed discussion of antenna construction by assuming the following conditions. You have a portable receiver with a built–in whip antenna and, for any of the reasons noted , you decided to erect an external antenna.

THE VERTICAL WHIP ANTENNA

Omni-directional. Impedance: 75 ohms. Vertical. Broad band. End-fed.

This antenna is ideal for city and apartment dwellers with limited space. It's effective and simple to erect. It can be made either from an automobile antenna or from a length of small diameter tubing, such as aluminum. Commercial versions often include a combination tuner and amplifier. The lead-in can be either shielded co-axial or regular insulated wire.

Since it is omni–directional, best results are obtained by locating it on the roof, a chimney or a high pole. Extending the antenna from a window sill or mounting it alongside a building limits the directions from which a signal can be received. However, provided the desired signal is unobstructed, this is an easy solution. Being a vertical antenna, it is very susceptible to electrical noise. If the listener lives in an area where electrical noise is not too high, using insulated wire as a lead-in increases the effective length of this particular antenna—and its ability to capture signals. Figure 4 shows a typical installation of a whip.

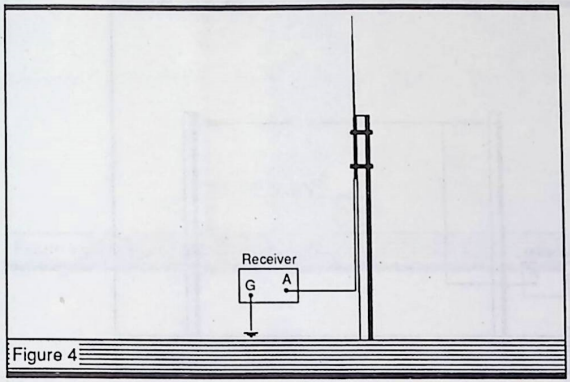

Figure 4

THE INVERTED L OR MARCONI ANTENNA

Omni-directional. Impedance:50–75 ohms. Horizontal. Broad band. End-fed.

The horizontal section should be about 17 metres (50 feet) long. See Figure 5.

Attach the insulated lead–in directly to the built-in whip antenna with alligator clips. The whip antenna should be in the collapsed position to reduce the amount of noise pickup. If this arrangement results in signal overload, wind the lead-in around the base of the whip antenna (don't remove the insulation!) a few times and secure it with electrical tape. This is called inductive coupling.

Portable receivers equipped with an external antenna terminal or jack often have a signal reducing device, called an attenuator, in the input of the receiver. The attenuator ensures that the strength of the signals from an external antenna will be comparable to those obtained from the receiver's built-in whip antenna. This in turn reduces the possibility that the external antenna will produce a signal overload in the receiver.

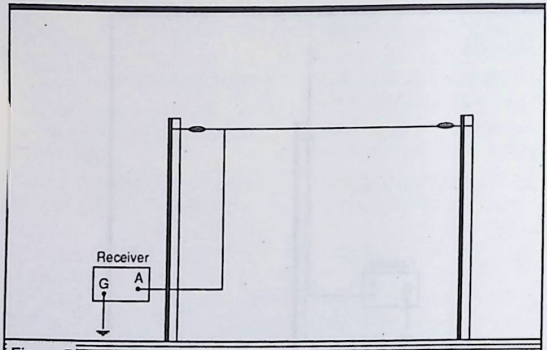

Figure 5

THE VERTICAL ANTENNA

Omni-directional. Impedance: 52 ohms. Vertical. Broad band. End-fed.

It consists of a wire, 6.1 to 18.3 metres (20 to 60 feet) long, which can be suspended from the overhang of the roof, or supported by a pole, or hung from the branch of a convenient tree. Anchor the lower end of the antenna securely to the ground. Because the lead-in is very short, the amount of noise pickup is kept to a minimum. However, the closer the antenna is to the house or other obstructions, the more its omni-directional properties are reduced. If you are unable to receive the desired signal, install the antenna as far away from obstructions as possible and use a shielded lead-in. Figure 6 shows a typical installation.

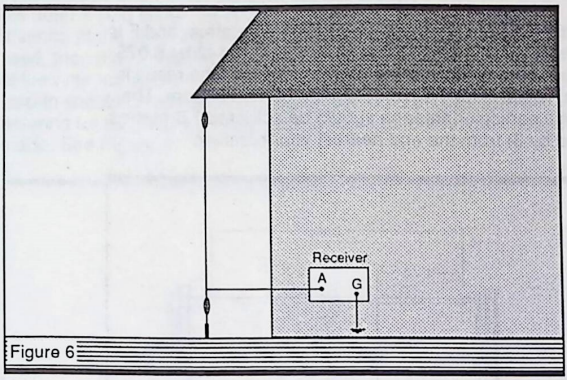

Figure 6

THE WINDOM ANTENNA

Omni-directional. Impedance: 75 ohms. Horizontal. Multi-band. Off-centre-fed.

The Windom is a half-wavelength antenna cut for the lowest frequency band in which it is to be used. The lead-in is connected about one-third from the end of the antenna to provide a good impedance match. If you have sufficient space, make the Windom about 38.4 metres (126 feet) long and connect the lead-in 12.8 metres (42 feet) from the end nearest your receiver. (See Figure 7.) This should provide good reception in all international shortwave bands from 11–75 metres.

For maximum reception, the Windom may be cut to a particular shortwave band, according to the following formula:

$$L = \frac{142}{F}$$

where L is the required length of the antenna in metres, and F is the known frequency in MHz. For example, divide 142 by 6.075 MHz (the centre frequency for the 49 metre band). The result is 23.4 metres, which is the horizontal length of the Windom. The lead-in for this particular antenna should be soldered 7.8 metres (23.4 divided by 3) from the end nearest your receiver.

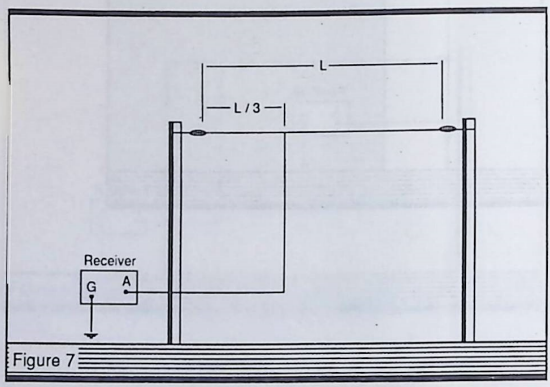

Figure 7

THE HALF-WAVE DIPOLE

Directivity: right angles to the signal. Impedance: 75 ohms. Narrow band. Centre-fed.

This antenna gives best results in a particular metre band. Start by determining the centre frequency within the desired metre band and then calculate its wavelength.

The total length of the antenna is half the wavelength of the centre frequency. The half-wave dipole is split in two at the centre by an insulator. The result is two sections each a quarter of a wavelength long: in other words, it is a quarter-wavelength from the centre insulator out to each of the insulators at either end of the antenna.

The 75 ohm lead-in can be either co-axial or twin lead. If a co-axial lead-in is used, then the centre conductor should be connected to one half of the antenna at the centre insulator and the outer shield should be connected to the other half of the antenna at the other end of the centre insulator. If twin lead is used, then the conductors should be connected one to each side of the antenna at the centre insulator. As with the Windom, the lead-in should be allowed to drop freely at right angles from the antenna for as great a distance as possible before any bends are made. See Figure 8.

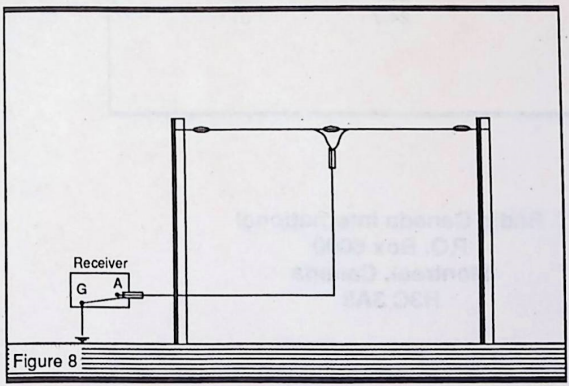

Figure 8

Since the half-wave dipole is cut for a specific frequency band, you must erect a dipole for each band you wish to use. If you erect a series of half-wave dipoles, connect all the lead-ins to a multi-position switch, available at stores which sell electronic parts and supplies or at ham radio shops. This will make it easy to select the antenna to match the band to which the receiver is tuned. Table 2 contains measurements for constructing a half-wave dipole for the various shortwave bands. Note that these are the overall lengths, so the centre insulator should be located at the middle point for each band. The lead-in should run from the antenna at right angles for as great a distance as possible before bending toward the receiver location.

Metre Band	Overall Length	
	Metres	Feet
11	5.8	19
13	7.0	23
16	8.4	27
19	9.8	32
25	12.7	42
31	15.6	51
41	20.8	68
49	24.7	81

Table 2

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